THE EFFECTS OF MILITARY AND OTHER GOVERNMENT SPENDING ON THE COMPUTER INDUSTRY: THE EARLY YEARS

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PREFACE

This paper is a study of the effects of government investment on the U.S. computer industry. Specifically, this report focuses on the nascent years of computers (the late 1940s through mid 1950s) and the role that the government, especially the Department of Defense, played as a sponsor of university and corporate computer research and production efforts. The report examines the position of dominance the U.S. held in the computer industry by the late 1950s and retains today, attempting to analyze how much of this is due to early government support.

This report does not attempt to analyze or make recommendations regarding the economic potential of any national "technology policy." The great success of the computer industry, which owes its start to government investment, may be viewed by some as evidence supporting such a policy. But the early computer successes were the results of "spillovers" of military investments and applications, rather than the economic fruits of government targeting. The analysis of the relative merits of a national technology policy is a subject for further, more extensive research for which this paper merely serves as a case study.

There are many, many peripheral topics of interest that are beyond the scope of this paper, but are interesting unto themselves. For example, why did some firms fail while others succeeded in the early computer industry? How did the rapidly declining costs of computational power affect industry demand and growth? These topics are worthy of study by any economist or business person but are not directly addressed here.

This paper is actually one case study that is part of a broader effort toward analyzing the effects of defense spending on the U.S. industries and the economy as a whole. Both potential positive and negative effects were examined in a series of industry-by-industry case studies analyzing the costs of military spending. The specifics as to what constitute "positive" and "negative" effects are delineated in the what constitute "positive" and "negative" effects are delineated in the body of this report. This larger problem was tackled in RAND Graduate School's Civil and Military Technology Workshop in the Spring of 1988. Each of the five students in the class conducted a case study to analyze the government's role in the successes and failures of particular industries. The five industries examined are the early computer industry (here), parallel processing in the modern computer industry, semiconductors, numerically controlled machine tools, and commercial aircraft. The workshop was partly supported by funding provided by the Pew Charitable Trusts of Philadelphia.

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I. INTRODUCTION

In 1987, the U.S. Computer Industry was a $57.5 billion business, constituting a 38% share of the world computer market.[1] The 1988 forecast is that the industry will increase 10% in current dollar value in 1988 for a total value of $63.2 billion.[2] This growth prediction is considered modest by some sources, who predict combined software-hardware growth to be as high as 18% in 1988 compared with 1987, which would make the computer industry the fastest growing U.S. industry for 1988--a position it has held before.[3]

What caused this dominance of the U.S. as the world's leading computer producer and of the computer industry as one of the leading U.S. industrial efforts? Many factors have contributed to this remarkable U.S. success, including such supply factors as a concentration of U.S. expertise in high technology; demand factors such as an information explosion requiring the use of computers, and many more. But one key advantage the U.S. has held is an "early lead" in the computer industry, and once having achieved this, continuing to innovate and build on their early near-monopoly to maintain growth and dominance.

How did the U.S. become the early dominant manufacturer in an industry of exploding growth? Some success is due to the vision of such early pioneers as Eckert and Mauchly, makers of ENIAC, the first commercial computer,[4] and Thomas Watson, the founder of IBM Corporation.[5] These men foresaw the applications of computer technology

[1] *U.S. Industrial Outlook 1988 - Computers and Software*, p. 30-2.

[2] Ibid.

[3] Mitch Betts in "Feds: Computer industry fastest growing in '88," *Computerworld*, Vol. 22, No. 2, Jan. 11, 1988, p.76.

[4] Barbara Goody Katz and Almarin Phillips in "The Computer Industry," *Government and Technical Progress*, ed. by Richard R. Nelson, Pergamon Press, New York, 1982, p. 169.

[5] Ibid; and many other sources.

beyond scientific and military applications into the commercial realm, especially in such large and lucrative applications as insurance and banking. But such vision was not active until the computer was in its "second generation."[6] There would have been no second generation computers without first having a first generation of these machines. And the early success of the U.S. in first generation computers owes much to the involvement of and funding by the U.S. government, particularly the Department of Defense. Indeed, virtually every U.S. first generation machine, except one, and most university and corporate research efforts were funded by the U.S. government.[7] Additionally, the government was responsible for organizing and providing location sites for early meetings involving the key researchers in early computer technology. Much useful information was shared freely at these open forums.

It seems clear that the U.S. computer industry owes much of its early--and therefore current--success to government investment. How exactly can one analyze the potential effects of government investment? In our civil and Military Technology class we developed a framework for analyzing conditions under which the government should invest in an industry, and where this investment is primarily made for a military purpose, how military spending costs should be adjusted up or down to account for the negative effects or additional benefits received by particular industries as a result of military spending.

In a free market economy such as ours, some form of market failure is required to bring in the government as a funder of research and development. This market failure can assume many forms, to be discussed later in the body of this paper. The costs of military spending can be adjusted either up or down, depending on whether this spending had a negative or positive effect on the civilian industry in question. These "additional costs" and "additional savings" provide the framework for analysis and are delineated further in this paper.

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[6]Barbara Goody Katz and Almarin Phillips in "The Computer Industry," *Government and Technical Progress*, ed. by Richard R. Nelson, Pergamon Press, New York, 1982, p. 169.

[7]Kenneth Flamm in *Creating the Computer*, The Brookings Institution, Washington, D.C., 1988; and various other sources.

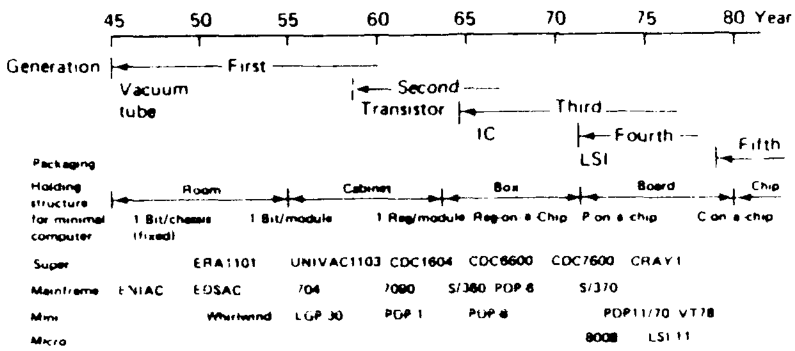
II. THE HISTORY OF THE EARLY COMPUTER

A DEFINITION

What exactly is a computer? Most people can provide answers by example, especially since personal computers have become so ubiquitous. A more precise answer lies in the name "computer" itself, which is self-defining. A computer, obviously, is something that performs computations. The definition of a computer given by Webster's dictionary was changed in 1955 from "one who performs a computation" to "one or that which performs a computation." The addition of those three words reflects a revolutionary change in mankind's methods of manipulating numbers that has had widespread effects.[1] The human computer and his mechanical calculator have been joined by the electronic computer. Also of great use has been the electronic calculator, which performs many of the same functions as a calculator in its ability, refined through time, to perform any sequence of keyed-in arithmetic operations. The key distinction between "calculator" and "computer" is that computers have the ability to store programs, unlike calculators which merely perform arithmetic operations as they are keystroked in.

Throughout this paper and through any readings on the history of computers, one encounters references to the "generational" concept of computers. This refers to a system of categorizing computers chronologically based on some major technological breakthrough of the time. For example, first generation machines were built on vacuum tube technology, the transistor occurred the dawn of the second generation, integrated circuits marked the third generation, and large scale integration was the salient feature of the fourth generation. Figure 1 below provides a timeline, important physical characteristics, and examples for each of the generations of machines.

[1] W.A. Atherton in *From Compass to Computer*, San Francisco Press, San Francisco, CA., p. 268. (Paraphrased).



SOURCE: Atherton's From Compass to Computer.

Fig. 1--The Generational Concept in Computers

FROM THE ABACUS TO THE FIRST FUNCTIONING COMPUTER

From ancient times methods have been sought to mechanize the process of arithmetic. One of the oldest, the abacus is still with us. The Scottish mathematician John Napier published his tables of logarithms in 1614 and seven years later an Englishman, William Oughtred invented the tool that acted as the predominant aid to mathematicians and scientists right up until the 1960s--the slide rule.

Precision mechanical engineering had progressed sufficiently for the volume production of mechanical calculators to begin early in the nineteenth century, and by the end of that century Herman Hollerith had developed the punched-card system for data processing.[2] (See Table 1 below for significant achievements in the pre-automatic calculator era.)

The first person to come up with a design for an automatic calculating machine was Charles Babbage in England. In 1822 he began by demonstrating a small "difference engine" that could calculate difference tables for quadratic functions. By 1843, Babbage was at work designing an "analytic engine," the first design for a genuine computer.

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[2]W.A. Atherton in *From Compass to Computer*, San Francisco Press, San Francisco, CA., p. 268. (Paraphrased.)

Table 1

MECHANICAL CALCULATORS[a]

c. 1000 BC	Abacus
1617	J. Napier, Napier's bones (multiplication aid).
1621	W. Oughtred, slide rule.
1623	W. Schickard, mechanical addition/subtraction, destroyed by fire and project abandoned.
1642	B. Pascal, first practical calculator (+/-), over 50 built. Wheels and gears.
1671	G. Leibniz, reliable calculator, all basic operations
c. 1820	C. Thomas de Colmar (Alsace), commercial production, 1500 machines built over 60 years.
1875	F.J. Baldwin, variant of Leibniz wheel. Manufactured by W.T. Odhner. Odhner-type machines made in large numbers.
1885	W.S. Burroughs, printing calculator, key-set for numbers, handle for operation.
1886	D.E. Felt, comptometer, keyboard machine.
1890	H. Hollerith, punched-card machine.

[a]Source: Atherton's From Compass to Computer.

It was to be a full-scale, general purpose mechanical computer with memory, arithmetic unit, punched cards allowing input and output, and card-controlled programs that allowed iterations and conditional branching. The design and the incredible vision behind it still stand as a remarkable tribute to a man who was about a century ahead of his time.[3] After Babbage at least three attempts were made to design a mechanical computer. The last was probably that of Louis Copuffignal of France in the 1930s. With that the dream of a Babbage-like computer was almost at an end. In the meantime, corporations manufacturing mechanical calculators were forming, merging, and preparing themselves for entry into what was to become the computer industry.

In 1896, Herman Hollerith, a former census worker who had invented the punched-card machine, formed the Tabulating Machine Co. In 1911, this firm merged with another company and became the

[3]Herman H. Goldstine in *The Computer from Pascal to von Neumann*, Princeton University Press, Princeton, N.J., 1972, pp. 19-22.

Computing-Tabulating-Recording (C-T-R) Co. In 1914, Thomas Watson, who had been fired from National Cash Register (another calculating machine company), took over C-T-R as president. Ten years later he changed its name to International Business Machines.

Concurrently, James Powers, another former census engineer, founded the Powers Tabulating Machine Co. In 1927, his company merged with one called Remington Rand to become a preeminent producer of typewriters and adding machines. Thus the commercial era of calculators from 1900-1945 was dominated by adding machines, tabulating machines, cash registers, desk calculators, and differential analyzers.[4]

By World War II the concept of a machine to perform calculations automatically had become a near necessity. Vast amounts of repetitive calculation were needed to compile ballistic tables for shells and bombs. This era, known as the "development period" of computers, is the "pre-first generation" of computers that was almost entirely funded in the U.S. by the military or other branches of the government. Following this, we have the generational concept as a classification system for computing eras. The first generation machines were those first developed commercially in the early 1950s; today we use computers of the "4.5 generation" and are planning and developing machines for the fifth generation and beyond.

The Moore School of the University of Pennsylvania, under government contract with the Aberdeen Ballistic Research Laboratory, developed and built a differential analyzer for the production of firing tables as early as 1934. A commercially manufactured MIT machine was delivered to Aberdeen in 1935. In 1937, Howard Aiken, a graduate student at Harvard, prepared a memorandum on digital computation devices. This work came to the attention of Thomas Watson, president of IBM, who funded Aiken's project, assigning developmental responsibilities to Clare Luce, a leading IBM engineer. After the U.S. entered World War II, Aiken was made a commander in the Navy and assigned to complete his work. The Automatic Sequence Control Calculator (Mark I) was completed in 1944 and donated to Harvard by IBM.

[4]B.G. Katz and A. Phillips in "The Computer Industry," *Government and Technical Progress*, op. cit., pp. 163-165.

(Note: this is the only early machine uncovered in research whose primary sponsorship and funding was some source other than the government.) The Mark I may be regarded as the first functioning computer, but it was largely mechanical (rather than electronic). Subsequent models, the Marks II, III, and IV, were built for the Navy and Air Force at Aiken's Computation Laboratory after the war.[5]

Also in 1937, Dr. George Steibitz of Bell Telephone Laboratories began work on the use of telephone relay devices in calculating equipment. By 1940, the National Defense Research Committee and the Office of Scientific Research and Development (both government agencies) were supporting Steibitz's development of the Bell Relay calculator.

This review of the pre-computer era has been brief and quite incomplete; Table 2 outlines briefly but more comprehensively the major developments of this period.

THE DEVELOPMENT PERIOD: EARLY RESEARCHERS AND THEIR MACHINES

In 1945, the big breakthrough occurred in that the ENIAC (Electronic Numerical Integrator and Calculator) actually worked! Developed also at the Moore School under contract with Aberdeen Ballistics Laboratory. ENIAC was the brain child of John Mauchly and J. Presper Eckert, in a project directed by John Brainerd and Herman and Adele Goldstine as well as others at the Moore School. ENIAC was similar to the Mark I and the Bell relay computers in that it was digital, but unlike those earlier models it was fully electronic, rather than mechanical or electromechanical, and capable of computing at speeds several hundred times faster than that of any electromechanical or relay-type machine.[6] ENIAC provided a great technological impetus to the computer industry even though the original version had no commercial applications. The government, in sponsoring the many areas of research that led to the ENIAC, did much more than it had intended. A cadre of engineers and scientists with mutual interests had been developed. Among

[5]Ibid.

[6]Kenneth Knight in "Changes in Computer Performance," *Datamation*, September, 1966, pp. 40-54.

Table 2

DEVELOPMENT PERIOD COMPUTERS, PRE-ELECTRONIC[a]

Computer	Date Start–Operational	GP or SP	Radix	Relays	Valves	Stored Program	Memory Type	Memory Capacity	Word Length	Speed +	Speed −	Speed ×	Speed ÷	Remarks
Zuse, Z1	1934–1938	G	2	Mechanical		No	Mech.	16 words	24	1.0 s	1.0 s	5 s	5 s	Working for tests only, floating point
Zuse, Z2	1938–1939		2	Yes	No	No	Mech.	16 words	16	0.2 s	0.2 s	3 s	3 s	Electromechanical fixed point, working for tests only
Zuse, Z3	1939–1941	G	2	2600	No	No	Relay	64 words	22	1.0 s	1.0 s	4 s	4 s	Floating point keyboard/lamps I/O
Bell/Stibitz Model I Complex Number Calculator	1937–1940	S	2	450	No	No	Crossbar switches	10 registers						Remote access
Bell Model II Relay Interpolator	1940/41–1943	S	Bi-quin	440	No	No		6 registers						Self-checking arithmetic
Bell Model III Ballistic Computer	1942–1944	S	Bi-quin	1335	No	No		10 registers						100% self-checking
Heath Robinson	1942–1942	S		Yes	30 to 80	No								Gifford line printer O/P
Colossus Mk 1	1943–1943	S	Bi-quin	Yes	1500	No								Specialized towards Boolean calculations
Colossus Mk 2	1944–1944	S		Yes	2500	No								Conditional branching
Harvard Mk I ASCC	1939–1944	G	10	2000–3000 wheels		No	Relay, tape, switches	72 accumulators 60 constants	24	0.3 s	0.3 s	6 s	11.4 s	Largely mechanical
IBM, Pluggable Sequence Relay Calculator	–1944			Yes	No	No								

[a]Source: Atherton's From Compass to Computer.

them was John von Neumann, who became associated with the ENIAC project in August, 1944. With Mauchly, Eckert, and Herman Goldstine, von Neumann developed the concept of the "stored program" computer, with logic instructions stored in memory so that they could be modified arithmetically without a manual resetting of thousands of switches.

Perhaps the most significant influence in the yet-to-be-born computer industry in the 1945-46 period came from a six week course, "Theory and Techniques for the Design of Electronic Digital Computers" given at the Moore school in the summer of 1946. Significantly, this course was sponsored and funded by the office of Naval Research and the Army Ordnance Department. Attendees included representatives of the Army, Navy, National Bureau of Standards, MIT, Columbia, Harvard, the University of Pennsylvania, the Institute for Advanced Study (at Princeton), Cambridge, Bell Labs, National Cash Register, General Electric, and other companies. These government-sponsored knowledge forums were followed by other conferences and significant advances in development era machines. EDSAC, developed by Wilkes at Cambridge, was based on the Moore School Course. Eckert and Mauchly improved on ENIAC with EDVAC, which was supported by an Army ordnance contract. SEAC, developed by the National Bureau of Standards for the Census Bureau and IAS, developed by von Neumann for Army Ordnance and RCA Labs are examples of the many developers and machines developed under at least partial government sponsorship in this era.[7] This would include the Johnniac computer (named after John von Neumann, who aided in its design), developed at RAND in the early 1950s entirely under Air Force sponsorship.[8]

From 1944-47, IBM developed and produced, on government contract, a one-of-a-kind Selective Sequence Electronic Calculator (SSEC). IBM also made a few small, special-purpose relay computers for Aberdeen and the Dahlgren Naval Proving Grounds. AT&T's Bell Labs produced relay

[7]B.G. Katz and A. Phillips in "The Computer Industry," *Government and Technical Progress*, op. cit., pp. 167-168.

[8]F.J. Gruenberger in *The History of the Johnniac*, the RAND Corporation, Santa Monica, CA., 1968, RM-5654-PR, pp. iii-12.

computers for the Army Ground Forces Board and the Naval Research Laboratory. RCA was the co-developer of the IAS computer at Princeton. Dr. Jan Rajchman, an RCA scientist, is credited with development of the "selectron tube," an advanced electrostatic storage device commonly used at that time.[9]

Table 3 lists the major development era electronic computers and when they were developed. These computers led directly into the first generation machines, which unlike the development computers were developed mostly by corporations rather than universities and research centers.

[9] B.G. Katz and A. Phillips in "The Computer Industry," *Government and Technical Progress*, op. cit., p.169.

Table 3

DEVELOPMENT PERIOD ELECTRONIC COMPUTERS [a]

Computer	Date Start-Operational	GP or SP	Radix	Relays	Valves	Stored Program	Memory Type	Memory Capacity	Word Length	Speed +	Speed −	Speed ×	Speed ÷	Remarks
ENIAC	1943–1946	G	10	1500	19000	No	Selector switch "PROM" Vacuum tube	3600 digits 200 digits	10	0.2 ms	0.2 ms	2.8 ms	26 ms	First GP electronic computer built
IBM, SSEC	1945–1948	G	2	21400	12500	No	Electromag. paper tape, electronic	150 words 20000 words 8 words	20	< 1 ms	< 1 ms	20 ms		
Manchester University Mk I	1946–1948	G	2	No	500	Yes	Williams tube	32 words	32		1.2 ms			First GP electronic computer based on stored-program concept
Manchester University Enhanced Mk I	1948–1949	G	2	No	1300	Yes	Williams tube, drum	128 words 1024 words	40	1.8 ms	1.8 ms	10 ms		First use of index registers
EDSAC	1946–1949	G	2	No	3000	Yes	Delay line	512 words	"35"	1.5 ms	1.5 ms	6 ms		First stored-program computer to offer a user service. Division by subroutine
EDVAC	1945–1951	G	2	150	3600 to 5900	Yes	Delay line	1024 words	44	0.05 ms	0.05 ms	2.1 ms	2.1 ms	
ACE Pilot	1945–1950	G	2	No	1081	Yes	Delay line, drum (1954)	361 words 4096 words	32	0.54 ms	0.54 ms	2 ms	N.A.	
UNIVAC I	1947(?)–1951	G	2		5400	Yes	Delay line, mag. tape	1000 words	84	0.52 ms	0.52 ms	2.2 ms		
IAS	1946–1952	G	2		2300	Yes	Williams tube	1024	40	62 μs	62 μs	720+ μs	1100 μs	
Whirlwind	1947–1951	G	2		5000	Yes	Storage tube, electrostatic	1024 words 4096 bits	16	22 μs	22 μs	37.5 μs	71 μs	About 11000 crystal diodes. mag. core in 1953

[a]Source: Atherton's From Compass to Computer.

III. COMPUTER MARKET STRUCTURE AND PERFORMANCE

THE FIRST GENERATION: MAJOR SUPPLIERS AND THEIR MACHINES

Based on the records available, the firms that had at least the substantive technology base to enter, indeed, to found, the commercial computer industry were IBM, AT&T, RCA, Bendix, Boeing, Douglas, Hughes, North American Aviation, Northrop, Raytheon, Sperry, General Electric, Westinghouse, Philco, ITT, GTE, Burroughs, Friden, Monroe, National Cash Register, Remington Rand, Royal, and Underwood.

None of these firms elected to be the first venturer. Eckert and Mauchly were dismissed from the University of Pennsylvania in 1946 because of their interests in commercialization of the ENIAC and EDVAC concepts. They formed the Electronic Control Company in 1946 and the Eckert-Mauchly Computer Corporation in 1947. T.J. Watson had offered Eckert and Mauchly positions and a laboratory under their own management at IBM, but they turned him down. A rival firm, Engineering Research Associates, was formed in 1947 by personnel from the Naval Communications Supplementary Activity. Former Northrop workers formed the Computer Research Corporation.[1]

Eckert and Mauchly approached the Bureau of Census, which was known to be seeking a computer. Census requested bids and received them from Raytheon and Hughes as well as Eckert-Mauchly. The latter was awarded the contract in 1946. Thus the first non-military commercial computer contract also involved the government as client.

In 1947 Eckert and Mauchly received contracts from A.C. Nielson and Prudential Life Insurance for purchases of an EDVAC-like computer known as UNIVAC. But Eckert-Mauchly could not raise funds for development and went bankrupt in 1949. Remington Rand made an offer for the firm that was accepted in 1950. Unfortunately for Eckert and Mauchly, upper management at Remington Rand then tried to cancel all UNIVAC contracts. They were unable to do so with the Census Bureau, and the Census Univac

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[1] B.G. Katz and A. Phillips in "The Computer Industry," *Government and Technical Progress*, op. cit.

I was delivered in 1951, followed by sales of five more of the same machine to other government departments. Thus, with the loss of Prudential and Nielsen as clients, the government was still the sole customer of computers.[2] Government contracts also launched the aforementioned Engineering Research Associates, headed by William Norris. ERA started with a Navy contract for "special purpose," "highly classified" computing machinery and related work. This was immediately augmented by a contract for the Navy Atlas I, which was renamed the ERA 1101, to be followed by the 1102 and 1103. But ERA like Eckert-Mauchly was a financial failure and it too was acquired by Remington Rand.

INDUSTRY GROWTH AND DEMAND ISSUES

One must ask why these two early ventures into the computer industry failed and why other companies with both a technical and financial base weren't clamoring for entry. Examining Remington Rand in particular, William Norris and Mauchly concurred that their parent firm was too conservative and failed to make "the financial commitment that was necessary."[3] Obviously, the banks and other lenders failed to see the potential of computers by refusing resources to Eckert-Mauchly and ERA. How is such action reasonable in light of the tremendous growth and success of the computer industry?

First, except for Eckert, Mauchly, and some of the ERA folk, the general view prior to 1950 was that there was no commercial demand for computers.[4] T.J. Watson, Sr., President of IBM, with experience dating from at least 1928, was as acquainted with both business needs and advanced computational abilities as any business leader of the time. He felt that IBM's one SSEC machine "could solve all the important scientific problems in the world involving scientific calculations."[5] Watson saw only limited commercial possibilities. This view, moreover,

[2] Ibid; p. 170.

[3] Mauchly's deposition in "U.S. vs. IBM," 69 Civ 200, Defendant's Exhibits 280, 305, Transcript at 5721-23; part of anti-trust case in the 1960s.

[4] B.G. Katz and A. Phillips in "The Computer Industry," *Government and Technical Progress*, op. cit., p.171.

[5] William F. Sharpe in *The Economics of Computers*, Columbia University Press, New York, 1969, p. 185.

persisted even through some private firms that were potential users of computers, such as the major life insurance providers. Incredible as it seems to us with our crystal clear hindsight, a broad-based business need was simply not apparent in the early 1950s.

The perceived demand for computers in 1950 was about what it had been in 1945. As private firms saw it, the only demand was from government agencies such as the Census Bureau, the Naval proving grounds, the Weather Bureau, the Ballistics Research Laboratory, and others. A number of firms invested modestly in research relating to computer technology, but with the Eckert-Mauchly and ERA exceptions, none invested heavily in physical and human capital with a defined commercial objective. The technology and market had yet to merge in a significant way.

The technologist users (in government) and the technologist suppliers (in private firms) had coincident interests and were members of a common "fraternity." They attempted to prevail on their respective host organizations--whether government agencies or private firms--to supply funds to meet their scientific objectives. "Demand," therefore, was more in the form of budget requests for research and development investment, without regard to immediate returns on investment, than a demand for marketable computer hardware.[6]

Between 1950 and 1953, many companies ventured into the computer industry via government contracts but none committed to the market until IBM did so in 1953. As just stated, all failed to realize the tremendous lucrative demand for computing power that was just around the corner. A summary of these first generation machines and their producers is provided in Table 4.

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[6]Almarin Phillips in "Organizational Factors in R & D and technological Change; Market Failure Considerations," *Research, Development, and Technological Innovation*, edited by D. Sahal, Heath Press, Lexington, 1980.

Table 4

PRINCIPAL FIRST GENERATION COMPUTERS

Company and Year First Installed	Model	Commercial Operations Per Second	Thousands of Commercial Operations Per Dollar	Number Installed
Burroughs				
1950	-			
1951	-			
1952	-			
1953	-			
1954	204-205[a]	187.3	14.5	≥ 43
1955	UDEC II	10.7	0.9	n.a.
	E-101	2.3	1.3	n.a.
1956	-			
1957	UDEC III	20.9	1.5	n.a.
1958	220	1616.0	129.2	n.a.
1959	E-103	2.3	1.3	n.a.
General Electric				
1950	-			
1951	-			
1952	-			
1953	-			
1954	-			
1955	-			
1956	ERMA	n.a.	n.a.	≥ 30
1958	-			
1959	-			
Honeywell				
1950	-			
1951	-			
1952	-			
1953	-			
1954	-			
1955	-			
1956	-			
1957	DATAMATIC 1000	1455.0	19.6	n.a.
IBM				
1950	-			
1951	-			
1952	-			
1953	701	615.7	11.3	≥ 19
1954	650	291.1	45.4	≥1800
IBM (continued)				
1955	702	1063.0	22.1	≥ 13
1956	705 I-II	2087.0	27.7	≥ 31
"	704	3785.0	49.9	≥ 90
"	701 (CORE)	1807.0	32.2	n.a.
"	305	96.5	15.7	≥ 1,500
1958	709	10230.0	90.8	≥ 32
1959	705 III	7473.0	99.2	≥ 111
NCR				
1950	-			
1951	-			
1952	-			
1953	102A[b]	8.4	1.0	n.a.
"	107[b]	34.4	8.8	n.a.
1954	303	8.3	1.0	0
1955	-			
1956	-			
1957	-			
1958	-			
1959				
RCA				
1950	-			
1951	-			
1952	-			
1953	-			
1954	-			
1955	BIZMAC I & II	967.9	5.5	6
Remington Rand				
1950	1101[c]	301.8	15.4	3
1951	UNIVAC I	271.4	6.8	≥ 40
1952	-			
1953	1103[d]	666.2	18.9	20
"	1102[d]	240.0	12.2	3
1954	UNIVAC 60/120	1.5	0.5	n.a.
1956	1103A	1460.0	28.5	n.a.
1957	File 0	73.2	3.0	100
"	UNIVAC II	2363.0	52.6	n.a.
1958	File I	92.0	3.8	n.a.
"	1105	5527.0	80.1	n.a.

continued

[a] Developed and produced by Consolidated Engineering Corporation. Burroughs had produced a Lab Calculator in 1951.

[b] Developed by Computer Research Corporation. 1953 acquisition by NCR.

[c] Developed and sold by ERA prior to 1952 acquisition by Remington Rand.

[d] Developed by ERA prior to 1952 acquisition by Remington Rand.

Source: Kenneth E. Knight, "Changes in Computer Performance," Datamation (September 1966), pp. 45-46.

THE U.S. POSITION AS A WORLD PLAYER

By the end of of the 1950s the U.S was firmly in place as the dominant computer manufacturer in the world. This corresponds with the period for which demand for computational power, both nationally and world-wide, was beginning to grow exponentially. (See Figure 1 below.) In 1960 the U.S. had a whopping 78% share of an industry valued at $7.5 billion in constant 1982 dollars. It is not known exactly how much IBM's share of the total market was, either then or today. IBM, unsurprisingly, has not released its private records on these matters. However, by examining old annual reports, which are publicly available, and estimating, we can assume that IBM had at least a 50% share of the world market in 1960. (That figure is considerably less, no more than 10%, today.) I am not sure at what level a firm can be classified as a monopoly, but using Herscheiser index measures, the IBM of 1960 easily qualifies as a potential monopoly. By virtue of its dominance then of all the major U.S. firms, and of the U.S.'s world dominance, one could infer that the U.S. did have at least an oligopoly, if not a monopoly outright, on computers in the world market. The percent of U.S exports then, however, is much smaller than it is now, so the economic benefits reaped from this position are much less than they would be given the level of exports today.

Although the U.S. world share today is less than 40%, total U.S production in constant 1982 dollars now exceeds $50 billion, of which the value of exports total $17.4 billion, which represents 30% of the total. Much of this current, still dominant position is owed to the early prevalence of the U.S. government support of American research and development efforts and its position as the major procurer of equipment in the development era and first generation of computers.

IV. THE ROLE OF THE DEPARTMENT OF DEFENSE AND OTHER GOVERNMENT AGENCIES

WORLD WAR II AND EARLY MILITARY SUPPORT

The growth of high-technology industry in the United States is directly linked to World War II. The degree to which scientists and engineers were mobilized in support of the allied war effort and the scale of their activities were unprecedented.[1] As noted in the brief history of computer development given in the previous section, the first substantial investments in computer technology were motivated mainly by military objectives.

After the war, that support for research continued. From 1941 to 1945, the government spent an average of $600 million per year, almost entirely on military applications. In 1947, long after hostilities had ceased, the U.S. military spent $500 million (out of $625 million total federal research funds) on military R&D. Eighty percent of this went to industrial and university laboratories on contract.[2] Whereas before the war the government had paid for 15-20% of U.S. research, after the war it funded more than half of a vastly expanded national effort. As late as 1959, a Congressional committee estimated that 85% of U.S. electronics R&D (including computers) was paid for by the federal government. The critical role of technological success stories to the war effort guaranteed continued military and strategic interest in maintaining the accelerated pace of technology development in the tense postwar years.

The development of the computer was one of these wartime successes. It was no accident that the military services largely financed the postwar development of the computer in the 1950s. The military even indirectly bankrolled the aforementioned Eckert and Mauchly computer

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[1]Kenneth Flamm in *Targeting the Computer*, The Brookings Institution, Washington, D.C., 1987, p. 6.

[2]The President's Scientific Research Board in *Science and Public Policy*, vol. 1:*A Program for the Nation*, Government Printing Office, 1947, p.12.

projects. The military computer projects, as well as Eckert and Mauchly's daring bet on an as yet nonexistent commercial market, led to the first stirrings of interest in computers in the 1950s by business and industry. Indeed the first commercial computers were direct copies or adaptations of machines developed for military users.[3] This leads us into the "commercial era" of computers; the end of the first and the start of the second generation machines when the lucrative industrial uses of computing power became more obvious and private investment rapidly accelerated. At this time, the first great political clashes over technology policy in the United States occurred. Table 5 that follows reiterates much of the information contained in Tables 3 and 4, but it contains an important additional element -- the source of funding (military) for each of these early machines.

GOVERNMENT RESEARCH LESS SIGNIFICANT BY 1960

In the period or 1945-60, contracts between government and particular firms often opened broad technological opportunities for particular firms. After 1960 (after the "second generation" of commercial computers were on the market), the government had less direct and less significant effect on established firms. (See Figure 2, below, for the military share of R&D at some key companies from 1956-85.) The basic technology was by then diffused and a broad commercial market with large numbers of reasonably informed buyers had developed. Technological opportunities existed in commercial markets whether or not a firm had a major government contract.[4] The "slack" in research and development funds caused by the gradual lessening of government support through the late 50s and early 60s was picked up by private firms, as business leaders and private firms recoqnized the importance of this emerging industry. As businesses realized just how major the computer industry was becoming, they continued to dedicate larger shares of their incomes toward R&D. In particular, industry leader IBM reached a 50%

[3]Kenneth Flamm in *Creating the Computer*, the Brookings Institution, Washington, D.C., 1988, p. 29.

[4]B.G. Katz and A. Phillips in "The Computer Industry," *Government and Technical Progress*, op. cit., p.220.

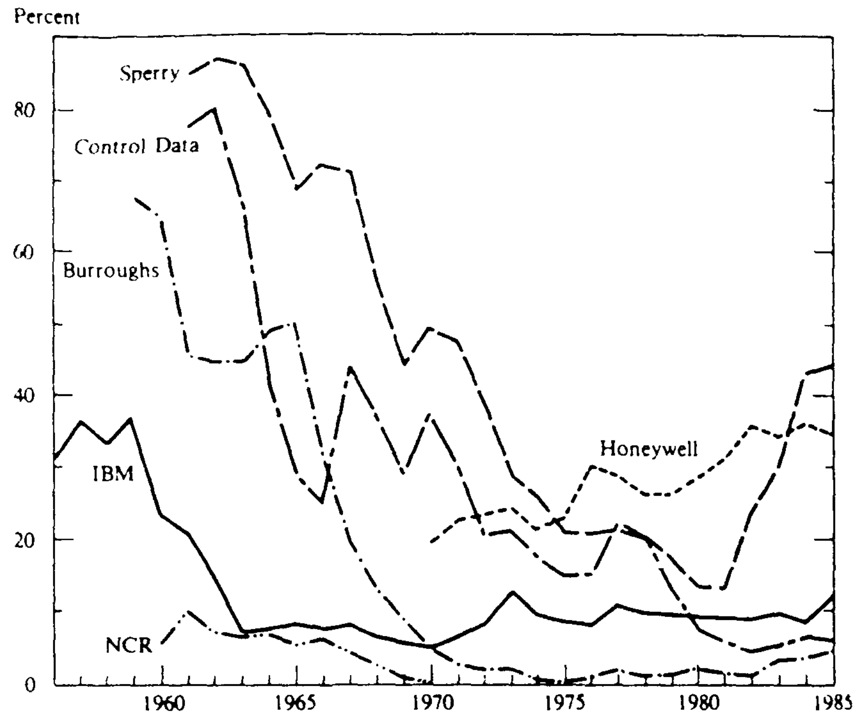
Table 5

EARLY COMPUTERS AND THEIR FUNDING SOURCES [a]

First generation of U.S. computer projects	*Estimated cost of each machine (thousands of dollars)*	*Source of funding*	*Initial operation*
ENIAC	750	Army	1945
Harvard Mark II (partly electromechanical)	840	Navy	1947
Eckert-Mauchly BINAC	278	Air Force (Northrop)	1949
Harvard Mark III (partly electromechanical)	1,160	Navy	1949
NBS Interim computer (SEAC)	188[a]	Air Force	1950
ERA 1101 (Atlas I)	500	Navy/NSA[b]	1950
Eckert-Mauchly UNIVAC	400–500[a]	Army via Census; Air Force	1951
MIT Whirlwind	4,000–5,000	Navy; Air Force	1951
Princeton IAS computer	650[a]	Army; Navy; RCA; AEC	1951
Univ. of Cal. CALDIC	95[a]	Navy	1951
Harvard Mark IV	n.a.	Air Force	1951
EDVAC	467	Army	1952
Raytheon Hurricane (RAYDAC)	4[illegible]0[a]	Navy	1952
ORDVAC	600	Army	1952
NBS/UCLA Zephyr computer (SWAC)	400	Navy; Air Force	1952
ERA Logistics computer	350–650	Navy	1953
ERA 1102 (3 built)	1,400[c]	Air Force	1953
ERA 1103 (Atlas II, 20 built)	895	Navy/NSA	1953
IBM Naval Ordnance Research Computer (NORC)	2,500	Navy	1955
Subtotal	15,933–17,333		
Other machines			
ASA Abner	n.a.	NSA	1952
Air Research OARAC (built by GE)	185	Air Force	1953
IBM 701 Defense Calculator (19 built)	425[d]	IBM, with letters of intent from 18 DOD customers	1953
Technitrol 180	500	NSA	1955
Naval Research NAREC	1,500	Navy	1956
NBS DYSEAC	n.a.	Army	1954
Copies:			
of IAS			
Los Alamos MANIAC I	250–298	AEC	1952
Oak Ridge ORACLE	250	AEC	1953
Rand JOHNNIAC	n.a.	Air Force (Rand)	1954
Argonne AVIDAC	n.a.	AEC	n.a.
Argonne GEORGE	500	AEC	1957
of ORDVAC			
Univ. of Ill. ILLIAC	300–500	Army	1952
Mich. State MISTIC	n.a.	n.a.	n.a.
Iowa State Cyclone	n.a.	n.a.	1959
of SEAC			
Univ. of Mich. (Willow Run) MIDAC (MIDSAC)	n.a.	Air Force	1953(1954)
FLAC	n.a.	Air Force	1953

[a]Source: Flamm's Creating the Computer.

AEC = Atomic Energy Commission
NSA = National Security Administration



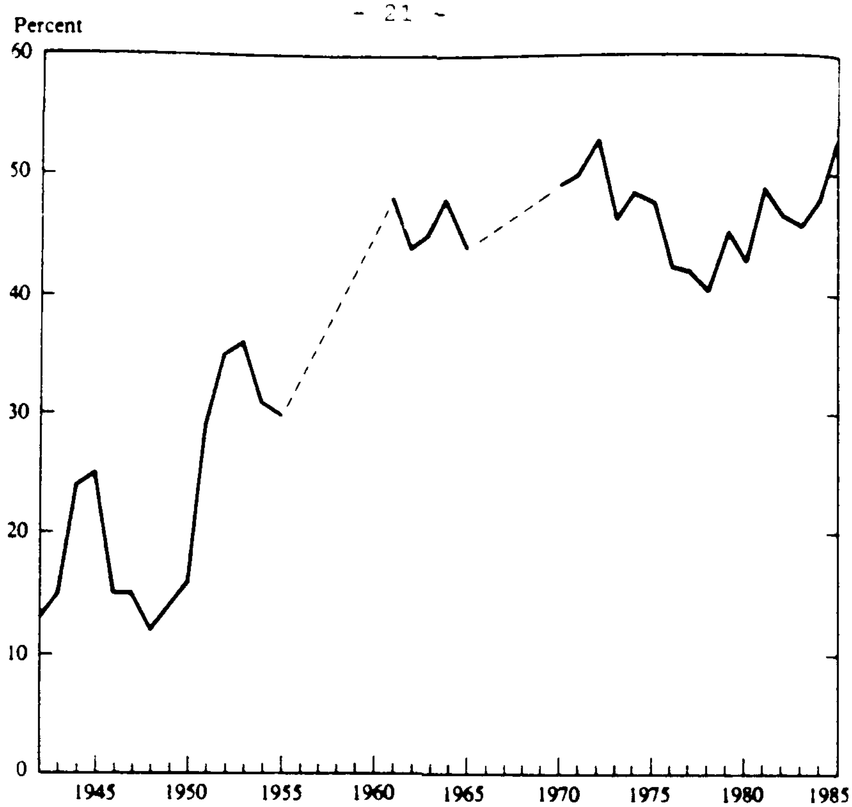
SOURCE: Flamm's Targeting the Computer.

Fig. 2--Defense Share of R&D Funding, 1956-1985, Selected Firms

level of R&D support during development of the 360 computer series in the 1960s, and spends even more today in an accelerated effort to maintain its premier market position. (See Figure 3).

This is not to say that government support, both for research and development and as a procurer, disappeared altogether with the advent of second generation machines. Government interest in improved technology for special purposes continued and augmented private R&D expenditures. However, until the advent of supercomputer research and development in the 1980s, the government after 1960 was a small, specialized supporter and customer rather than the major source of research funds and the major client.

Military interest in supercomputer development (including parallel processors), saw the return of major government support. That particular area is beyond the scope of this paper and has been addressed by another student in the Civil and Military Technology Workshop.



SOURCE: Harman's <u>The International Computer Industry</u>

Fig. 3--IBM's Research and Development Expenditures as a Percentage of Net Income, 1942-1985

However, it is significant to note that the major, established computer firms have chosen to rely on their private funds to augment government research money, and IBM, the world's leading manufacturer of computing equipment, has refused government support altogether. This is because the era of "shared information" characterizing the development era and first generation era of computers is long since over. It has been replaced by a private firm preference toward proprietary development.

V. THE MOTIVATIONS FOR GOVERNMENT SUPPORT

WHY GET INVOLVED? URGENT DEMAND AND MARKET FAILURE

When analyzing government support of an industry in a capitalist, free market environment, including military support, one must ask: What factors or market conditions cause a government to get involved? When military investment is heavily involved, the question has two answers: the special demands of national security, and market failure.

When the military in the U.S needs a particular weapons system or some particular technological capability, it does not order its request from some nationalized entity established to provide military goods and information. Rather, it contracts with one or more private firms to meet its needs. And the military is not overtly concerned with how their requests will help (or hurt) particular private firms in their established markets when it does its contracting. In times of war, I call these military needs "urgent demands," to signify their importance and to differentiate them from the "normal demands" customers have for products.

I view the military desire for computational power, both during and immediately following World War II, to be such urgent demand. The military wanted, indeed needed, computing power, and thus the computer was born and matured quickly. The government was not "targeting" the computer industry with its actions; it seems unlikely that anybody in the government was more prescient than the leaders of industry, who did not foresee the vast commercial computer market in the 1940s. Rather, the military was simply supporting, through sponsored research and colloquies of shared informations as well as through procurement, a technological advancement that it needed. It just happened that for this particular industry, computers, early public support paid off handsomely.

However, there are factors other than military needs that can cause a free market government to get involved and support private industry. These factors can be summed under the heading "market failure." As its name implies, market failure refers to the failure of normal market forces because of "unusual" characteristics of research or development in particular industries. When the free market forces fail, one can argue that this is a necessary (but not sufficient) condition for government intervention. Examples of market failure include the following list (which makes no claim to being comprehensive):

- Firms have no control over technology diffusion; therefore all underinvest.
- Firms incorrectly assess benefits due to valuing short-term benefits only; therefore underinvest.
- Capital markets fail; firms can't get loans.
- Fear of ruinous competition; heavy R&D expenses not recompensed by low prices forced by competition; firms underinvest.
- Product characterized by large economies of scale; small firms cannot succeed.

We can analyze military spending in a market failure framework; specifically, we can analyze characteristics of military spending on a particular industry and classify those characteristics as to those which impose additional costs on military spending and those which provide benefits which would cause us to adjust the military costs downwards.

THE ADDITIONAL COSTS OF MILITARY SPENDING

The Civil and Military Technology Workshop Class identified four conditions that could adversely affect an industry contracting with the government. These conditions, and whether they apply to computers, are outlined here.

Security Rules Restricting Private Resources

If the government places security restrictions on information related to research and development of a technology or on a product itself, the firm contracted with cannot use this capability in any of their other products and the employees used on and knowledge gained from this classified project will be less useful to the firm than if they had been engaged in some "normal" (i.e., unclassified) endeavor. Indeed, firms dealing with any emerging technology require open communication and a free flow of information if progress is to be made.[1] Does this apply to the early computer industry? While intuition says "probably so," history teaches us exactly the opposite. While early research and development efforts were in support of World War II and other military efforts, this era was marked by a free flow of information amongst the computer development players. Flamm[2] and Katz and Phillips[3] argue that the free flow of information provided via government-sponsored newsletters and informational meetings was key to the rapid computer development in the late 40s. Additionally, none of the early machines contracted by the government were classified after World War II. It therefore seems that this particular additional cost does not apply to the early computer industry.

Ruination of Management by Government Contracting

Some argue that the management of companies dealing with the government as a principal client are often ineffective in competitive commercial competition. This "truth" is hardly universally accepted. Whether true or not, however, it does not seem to apply to the computer industry -- especially not today!

Mauchly, co-inventor of the UNIVAC, and early computer pioneers William Norris and Henry Forrest, felt that Remington Rand faltered when it had the opportunity to become a premier computer manufacturer after being the recipient of early government contracts.[4] But this failure to capitalize is viewed as a lack of vision in recognizing a commercial market rather than failure caused by previous work with the government.

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[1] *Scientific Communication and National Security*, Committee on Science, Engineering, and Public Policy, National Academy of Sciences, National Academy Press, Washington, DC, 1982.

[2] Kenneth Flamm in *Creating the Computer* and *Targeting the Computer*, op. cit..

[3] B.G. Katz and A. Phillips in "The Computer Industry," *Government and Technical Progress*, op. cit., p.220.

[4] Ibid., p. 170.

Monopsonist Government Forces Prices to Be Lower than True Costs

The government was clearly the monopsonist purchaser of computers in the late 1940s! Nobody else was buying any. Yet there is no indication that the government paid anything less than the full cost of the computers they ordered to be developed. Further evidence against this negative element of military contracting is the very healthy and competitive computer industry that had developed by 1960 and continues to grow today. It is true that several key computer ventures went bankrupt in the late 40s. But these, such as Eckert-Mauchly and ERA were attempting private financing of R&D and commercial contracts when they failed. Their government contracts seem to have helped keep them afloat (for as long as they did survive) rather than hurt them.

Reverse Leftovers - Leftunders

The concept of "leftunders" refers to a complete inability to transfer or otherwise utilize resources from a government development project within an industry to the commercial sector of that industry. One would expect this where the product is not "dual use," meaning that with few modifications a product has commercial as well as military applications. (This term is popular within the CoCom nations' list of proscribed products and technologies; CoCom being a U.S.-initiated organization of free-world countries who agree in principle to deny communist bloc nations access to certain key high-technology goods and information.)[5] The computer certainly is a dual-use product. There is nothing other than programming that distinguishes a computer that optimizes military targets from one that processes employees payroll. Therefore, the computer industry is not one that qualifies for having "leftunders."

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[5] *Balancing the National Interest, U.S. National Security Export Controls and Global Economic Competition*, Committee on Science, Engineering, and Public Policy, National Academy of Sciences, National Academy Press, Washington, DC, 1987.

ADDITIONAL SAVINGS (BENEFITS) OF MILITARY SPENDING

The Workshop class also identified seven conditions of government investment and procurement that could help private industry. These conditions and how the nascent computer industry fits into this framework are given here.

Economies of Scale

"Because the costs of developing a new product are for the most part independent of the scale on which that product is later produced, volume of sales and size of market can be crucial in determining the average cost of producing a technology intensive product. Given a particular new product, the largest producer may have the lowest costs."[6] Military spending is an advantage when government procurement provides sufficient volume of production for these economies of scale to be achieved. This, of course, requires that the product be one of dual-use if the commercial sector is to reap benefits from these scale economies. When analyzing this in regard to the computer industry, two questions must be answered, one contingent on the other. (1)Are there scale economies in computer production? (2)If so, were these abetted by early government research investment and procurement?

"Essential features inherent in all technology (and more generally in information) are economies of scale in its use,..."[7] Kenneth Flamm goes on to point out that computers are the classic example high technology product and that the industry is characterized by economies of scale. Has government support contributed to these? One can sensibly argue that financing of research and procurement by anybody contribute to the achievement of economies of scale. At its inception, the "industry" had only the government as client and investor; gradually commercial clients and internal financing replaced this. But clearly the government "kicked off" the achievements of economies of scale.

[6]Kenneth Flamm in *Creating the Computer*, op. cit., p.4.
[7]Kenneth Flamm in *Targeting the Computer*, op. cit., p.15.

Unable to Reap Exclusive Benefits of Private R&D

After commenting on economies of scale and scope, Flamm points out the disadvantages of size to a large firm: "New technology leaks out over time to competitors, who may then produce without incurring the costly initial investments in developing the technology."[8] One can infer from this that a large firm -- or any sized firm -- would be unwilling to invest too heavily in R&D; this slack could (should?) be picked up by government investment shared amongst all players.

As in the economies of scale example above, computers are the classic example industry of this phenomenon. One big case would be the original IBM PC which was a smashing, albeit short-lived, success. The PC clones quickly swallowed much of IBM's market share, reaping financial benefits similar to IBMs without having IBM's associated R&D expenses. (However, IBM's "temporary monopoly" economic benefits were so large that further research and development was, and is in these cases, encouraged rather than discouraged.)

Clearly, military research and development dominated the early computer industry. That this investment aided an industry that was not going to fund its research privately (at least initially) is also clear. However, the reasons for this investment have little or nothing to do with being an economic policy for an industry experiencing market failure; rather they are rooted in military requirements.

Public Risks and Benefits Unequal to Private Risks and Benefits

For many industries, the "societal risk" in investment is less than the sum of the individual risk as perceived by the member firms of the industry. The flip side of this coin is that benefits to society can be greater than the sum of benefits as perceived by individual firms. (A reverse synergy.) The issue discussed above issue of nonappropriability of private R&D fits into this category. When firms are unwilling to invest in R&D for fears the new technology will be quickly copied, the true benefits as perceived by society are not realized.

[8]Kenneth Flamm in *Creating the Computer*, op. cit., p.4.

Computers again epitomize many high-technology industries in that this characterizes them. But again, the military reasons for support of the early government industry did not take this phenomena into account. Furthermore, the computer industry today is characterized by very high R&D levels of expenditure that have been common since the second generation. R&D expenditures in the computer industry are second only to those in the aircraft industry in a ranking of private investment by high-technology firms. I don't, therefore, believe that this particular market failure characteristic has effected the computer industry.

Technology Spillovers

Technology spillovers occur when the knowledge, manufacturing capability, and even the product itself from a government-procured product can be applied to similar commercial products. This is the very definition of dual-use technology and products, and seems to characterize all technology-intensive industries. "Much technology of industrial interest ultimately winds up in products of military utility and vice versa. (One is hard pressed to name a class of high-tech products that has absolutely no military significance, particularly when the underlying industrial base is linked to the capacity to fight a prolonged war.) Thus virtually any important technology can be justified in either economic or military terms."[9]

Of all of the additional benefits reaped from military spending, this is the one most realized by the computer industry. Virtually every one of the early commercial computers owed its design roots, if not the design in entirety, to an earlier computer developed for the government. It is this dual-use feature that begat commercial demand and thus the birth of not only a giant industry but a whole new industrial era: the information revolution.

[9]Kenneth Flamm in *Targeting the Computer*, op. cit., p.15.

Leftovers - Products and People

I don't distinguish sharply between spillovers and leftovers. One could be picky and say a "leftover" product from the military sector requires no modifications at all for adaptation to the commercial sector, but the distinction is trivial. Rather I will concentrate on the human resource aspect of leftovers: a significant benefit from military investment is achieved when the same persons who worked on some military project, and their knowledge, can be used with little or no retraining in the commercial sector. This is clearly true of the computer industry. At the top level, we see the developers of early government-funded machines, such as Aiken, Eckert, and Mauchly, going on to work for or found commercial ventures. Much of the staff of early commercial computer firms (or departments within firms) was gathered from university and private government research teams. Clearly the early (and present!) computer industry benefited from leftovers.

National Monopoly Rent/Preventing Foreign Monopoly

When an industry, via either government support or other means, can establish such dominance as to lead to a national monopoly in a certain industry, that is a benefit to the society of the monopolist nation. (Of course, this assumes that there are international sales of at least some level of significance.) For this to occur, there must be a dominant, if not outright monopolist, firm within the monopolist nation. The computer industry today is marked by stiff international competition, but that was not always so. As late as 1960, the U.S. had a 78% share of the world market. But was the U.S extracting monopoly rents in their foreign sales? That depends on whether one views the IBM of the 1950s as a monopolist rather than merely a dominant player. It is tempting to say there was no monopoly based on the number of firms in the business in the 1950s. Table 6 below lists the major players. But IBM had such huge market share that further analysis reveals that monopoly prices within the country as well as internationally possible. Table 7 lists the data processing revenues of major U.S computer firms as of 1963. As one can see, IBM has a whopping 73% of this U.S. total.

Table 6

PRINCIPAL FIRMS IN THE COMPUTER INDUSTRY,
FIRST TEN YEARS OF THE INDUSTRY[a]

Firms	Total Sales All Products (In Millions of U.S. $)
Remington Rand (Sperry)	696
IBM	461
Burroughs	169
Raytheon	182
NCR	259
RCA	941
Bendix	608
Philco	NA
Honeywell	229
SDS	NA
Xerox	NA

[a]Katz and Phillips in "The Computer Industry," *Government and Technical Progress*, Pergamon Press, New York, NY, 1982, pg. 215.

Table 7

DATA PROCESSING REVENUES, U.S. COMPUTER FIRMS, 1963 & 1986[a]

Firm	1963	1986
IBM	1244	49591
Burroughs	42	9341
Sperry	145	
Digital	10	8414
Hewlett-Packard	N/A	4500
NCR	31	4378
Control Data	85	3347
Wang	N/A	2669
SDS/Xerox	8	2100
Honeywell	27	1890
Data General	N/A	1288
Amdahl	N/A	967
General Electric	39	900
Cray	N/A	597
Philco	74	N/A

All figures in millions of U.S. dollars.
N/A - Not available or firm not in data processing at that time.

[a](Source: F. Fisher, J. McKie, and R. B. Mancke in *IBM and the U.S. Data Processing Industry: An Economic History*, Praeger Press, 1983, p.65.)

Failure of Financial Markets

When the financial markets fail to respond to the financing needs of entrepreneurial or established firms for some worthy industry, government financing is clearly called for. (The tricky part of that statement is "worthy" -- who best decides what is and isn't?) The earliest ventures into commercial computers, Eckert-Mauchly and ERA, went bankrupt because of lack of financing (Eckert-Mauchly in 1950, ERA in 1951).[10] While one may conclude that this is indicative of a general financial market failure in the nascent 50s computer industry, one must examine this in the context of the commercial market for computers as envisioned by almost everyone of that time. To be concise, almost nobody envisioned a commercial market for computers, including bankers and other financiers of the era. Therefore, I don't view the unwillingness of the financial markets to invest in the industry, at least until the commercialization of computers was envisioned, as indicative of financial market failure. Rather, the firms sponsored by the military and other government agencies in early computer production should view themselves as "lucky" to have received government funds, leading to early progress and development in the industry. I say "lucky" because this government investment had everything to do with military demands, and nothing to do with national economic policy!

[10] B.G. Katz and A. Phillips in "The Computer Industry," *Government and Technical Progress*, op. cit., p.170.

VI. CONCLUSIONS AND FORECASTS

A SUMMARY

Government activities have had a profound influence on the computer industry. In the period 1945-60, government support of research and development and contracts between government and private firms often opened broad technological opportunities for particular firms. (See table 8, below, which outlines principal developments in computer technology and that breakthrough's relationship to government support.) This extensive government investment was motivated by strong military and other national security interests, along with the needs of other government agencies such as the National Bureau of Standards. In some instances the affected firms seized these opportunities (such as IBM); their consequent growth and success can be attributed to their having had such opportunities. Conversely, other firms did not realize the potential that governmentally sponsored R&D and product demand made possible (such as Philco).

After 1960 -- after the "second generation" of commercial computers was on the market -- the government had less direct and less significant effects on established firms. The basic technology was by then widely diffused and a broad commercial market had developed. The swarming of firms into the market reflects these commercial possibilities. An industry had emerged.[1]

A SCENARIO - THE EARLY COMPUTER INDUSTRY SANS GOVERNMENT

It seems safe to predict that the computer industry would have eventually developed as a major international market without early government involvement. It also seems reasonable to assume that this wouldn't have happened until later than it did, perhaps significantly later. Business leaders, financiers, and most scientists did not foresee a market in the early 50s. Commercialization was only realized

[1]B.G. Katz and A. Phillips in "The Computer Industry," *Government and Technical Progress*, op. cit., p.220.

Table 8

PRINCIPAL DEVELOPMENTS IN COMPUTER TECHNOLOGY[a]

Concept	Approximate date	Early use of concept	Government funding for R&D	First sales to government	Comments
Components					
Rotating magnetic storage	Early 1950s	Developed by several organizations for use on first-generation computers.	Yes	Yes	ERA pioneered the technology for use by the National Security Agency
Magnetic core memory	Early 1950s	Whirlwind I at MIT	Yes	Yes	Memory Test Computer at MIT. ERA 1103 was the first production computer shipped with core memory.
Transistor	Late 1950s	TX-0 at MIT in 1956; IBM 7090 was first major commercial computer to use.	Yes	Yes	First transistors were used in military products. Other candidates are Manchester University MEG (1953); Bell labs TRADIC (1954).
Semiconductor integrated circuits	1964–65	Many computer manufacturers concurrently developed computers using ICs in the mid-1960s.	Yes	Yes	First such commercial machines shipped by SDS and RCA.
Design					
Stored program computer	1946	EDVAC report (University of Pennsylvania)	Yes	Yes	EDVAC report, joint product of Eckert-Mauchly, von Neumann. All three projects received government funding.
	1949	EDSAC (Cambridge University)	Yes	Yes	
	1952	IAS (Princeton University)	Yes	Yes	
Index register	1950	Manchester Mark I. Later other machines continued to advance effective address-calculating	Yes	Yes	Supported by British Ministry of Defence.
Error correcting code	1950	Hamming code, later used on Rice I computer.	Yes	Yes	Hamming worked at Bell labs. Rice computer supported by AEC.
Microprogramming	1951	EDSAC 2 (1958); the IBM 360 computers (1964); elements can be found in MIT Whirlwind (1951).	Yes	No	Concept introduced by M. Wilkes, Cambridge University. Whirlwind funded by government; System 360 a commercial project.
Interrupt mechanism	1953	ERA 1103	Yes	Yes	
Graphics display	1953	MIT Whirlwind	Yes	Yes	
Floating-point hardware	1955	IBM 704	No	Yes	Other possible claimants are Amdahl's WISC, at University of Wisconsin (1954), funded by university; CEC 205 (1954). First 704 shipped to AEC lab at Livermore in 1955.
I/O Processors:					
A. Data channel	1958	IBM 709	No	Yes	First 709 shipped to AEC Livermore lab.
B. Programmable I/O processor	1963	Control Data 6600	Yes	Yes	First 6600 shipped to AEC Livermore lab.
Redundancy	1957	SAGE air defense system	Yes	Yes	
Cache memories	1958	IBM 360/85 (1969)	No	n.a.	First commercial use.
Hardware pushdown stacks	1960	English Electric, KDF-9	No	No	Alternate U.S. candidate is Burroughs D-825 military computer.
Instruction pipelining	1961	IBM 7030 Stretch	Yes	Yes	
Multiple arithmetic units	1961	IBM 7030 Stretch	Yes	Yes	
Hardware protection	1962	BBN's PDP-1	No	No	
Virtual memory	1962	Atlas computer	Yes	Yes	Built by Ferranti from Manchester University design.
Multiterminal support	1962	BBN's PDP-1 system	No	No	
Tagged operands	1962	B5000?	No	No	Built by Burroughs.
Multiple central processors	1962	D-825	Yes	Yes	Military computer, built by Burroughs.

[a]SOURCE: Flamm's Creating the Computer

after the capabilities of the fully functioning, rapidly advancing government machines had been built. Who can say how long progress would have been delayed without the government as catalyst?

A less safe prediction is what the U.S. position in the industry would have been and would be today if the industry emergence had been delayed. It seems at least feasible, if not outright likely, that the U.S. would have been and would continue to be a less dominant player than it was and is in the true scenario. Other countries, particularly Great Britain, were involved in early computer development. By 1955, at least three countries other than the U.S. had electronic digital computers installed. (See tables 9.1 and 9.2, below.) Perhaps one of these other countries would have become a more preeminent player in the market.

Within the U.S., the particular firms who went on to success in the industry may have been different. (Would IBM have developed such an overwhelming market share?) The established firms as of 1955 owed their positions to government contracts. The set of major players may have been somewhat different if the government hadn't been involved.

Table 9.1

INTERNATIONAL USE OF COMPUTERS THROUGH TIME

	Total number of electronic digital computers in use[a]				
Year	*United States*	*United Kingdom*	*France*	*West Germany*	*Japan*
1950	2	3	0	0	0
1955	240	13	5	5	0
1960	5,400	217	165	300	85
1965	24,700	1,582	1,500	2,300	1,870
1970	74,060	6,269	5,460	7,000	8,800
1974	165,040	14,400	16,100	18,800	26,100

Source: Flamm's <u>Creating the Computer</u>.

Table 9.2

IMPORTANCE OF NATIONAL FIRMS IN INTERNATIONAL MARKETS

Year	*United States*	*United Kingdom*	*France*	*West Germany*	*Japan*
	Percentage of computers installed by U.S. firms				
1961	100	17	49	70	56
1966	100	51	51	72	35
1971	n.a.	50	50	78	32
	Percentage of computers installed by foreign firms				
1974	5	70–75	92–95	80–85	45

Source: Flamm's Creating the Computer.

CAN U.S. PREDOMINANCE CONTINUE?

The investment and support of the U.S. government certainly launched the computer industry, and established the dominance of the U.S. firms in this industry by 1960. Today, the U.S. has a shrinking (but still majority) share of a market that continues to grow rapidly. The major foreign threat today is no longer the British or French, but rather the Japanese. Japan, unlike the U.S., does have a national policy of targeting industries; the computer industry is one of the principal industries they have targeted.[2] However, U.S. government support of the computer industry is rising again in the 80s for the first time since the 1950s, principally because of military interest in super computers. (Refer to figure 2.) Clearly, because of the dual-use nature of all computing machinery, military spending in this industry has positive commercial benefits.

As other nations become more socially advanced and technologically sophisticated, it is only natural that they should take a larger share of important high-tech industries such as computers. However, in my own forecasts and those of real experts, I would not write off the U.S. as

[2]Kenneth Flamm in *Targeting the Computer*, op. cit., pp. 125-126.

the dominant country in the industry any time in the near future. The position of dominance obtained (via military support) in the 1950s has given the U.S. a catapult effect it is still feeling. With computerized components pervading all of the new, high-tech military weapons systems, government support is on the upswing again. And last but certainly not least, commercial computer firms have long since recognized the importance of their market and are investing as heavily as ever in continued research and development. (Refer to Figure 3.) As we analyze the pluses and minuses of government industrial support, let us not overlook the importance of unhindered, free market, private investment for maintaining the "correct level" of research and development in any industry.

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